ENGAGING IN A MULTIPLE-TRACK APPROACH TO BUILDING CAPACITY FOR 21ST CENTURY ENGINEERING, OPPORTUNITIES AND CHALLENGES FOR RAPID CURRICULUM RENEWAL

Dr Cheryl Desha

Queensland University of Technology, Brisbane, Australia (The Natural Edge Project Research Group)

Mr Karlson Hargroves

University of Adelaide, Adelaide, Australia (The Natural Edge Project Research Group)

ABSTRACT

'Complexity' is a term that is increasingly prevalent in conversations about building capacity for 21st Century professional engineers. Society is grappling with the urgent and challenging reality of accommodating seven billion people, meeting needs and innovating lifestyle improvements in ways that do not destroy atmospheric, biological and oceanic systems critical to life. Over the last two decades in particular, engineering educators have been active in attempting to build capacity amongst professionals to deliver 'sustainable development' in this rapidly changing global context. However curriculum literature clearly points to a lack of significant progress, with efforts best described as *ad hoc* and highly varied. Given the limited timeframes for action to curb environmental degradation proposed by scientists and intergovernmental agencies, the authors of this paper propose it is imperative that curriculum renewal towards education for sustainable development proceeds rapidly, systemically, and in a transformational manner. Within this context, the paper discusses the need to consider a multiple track approach to building capacity for 21st Century engineering, including priorities and timeframes for undergraduate and postgraduate curriculum renewal. The paper begins with a contextual discussion of the term complexity and how it relates to life in the 21st Century. The authors then present a whole of system approach for planning and implementing rapid curriculum renewal that addresses the critical roles of several generations of engineering professionals over the next three decades. The paper concludes with observations regarding engaging with this approach in the context of emerging accreditation requirements and existing curriculum renewal frameworks.

KEYWORDS

Dual track approach, curriculum design, model for deliberative and dynamic curriculum renewal, Systemic and intentional curriculum renewal, engineering education for sustainable development

INTRODUCTION

Living in the 21st Century

As a result of the impact of the first 200 years of the industrial revolution, the second and third decades of the 21st Century are shaping up to be characterised as the time in human history when the impact from our collective activities on our Earth grew to a scale that threatened the very conditions that support life as we know it – and furthermore – that this understanding catalysed a swift movement to significantly reduce environmental pressures while strengthening economies around the world.

Since 2002 the work of *The Natural Edge Project* and its partners has been to assist in achieving such a movement, by contributing to, and succinctly communicating, leading research, case studies, tools and strategies across government, business and civil society [1]. In this work the authors focused on five key pressures on the environment, namely reducing greenhouse gas emissions, reducing impacts on biodiversity and natural systems, improving freshwater management, reducing waste production, and reducing air pollution. In each of these areas pressures on the environment have reached levels previously unobserved throughout history and scientists are finding themselves analysing and attempting to quantify projections and predictions into unknown territory, often with an unknown number of variables to take into account.

As noted by authors from a variety of backgrounds such as Stern [2], Gore [3] and Diamond [4], the subsequent complexity demands urgent action across a variety of professions, cultures and geographical boundaries. Not only is the scale of environmental pressure creating impacts that will threaten the Earth's ability to sustain the conditions we have grown accustomed to, the change in these conditions will be challenging for economies around the world. As can be seen from Figure 1 the trends in GDP are now being replicated in the growth of direct and in-direct costs related to environmental damages.

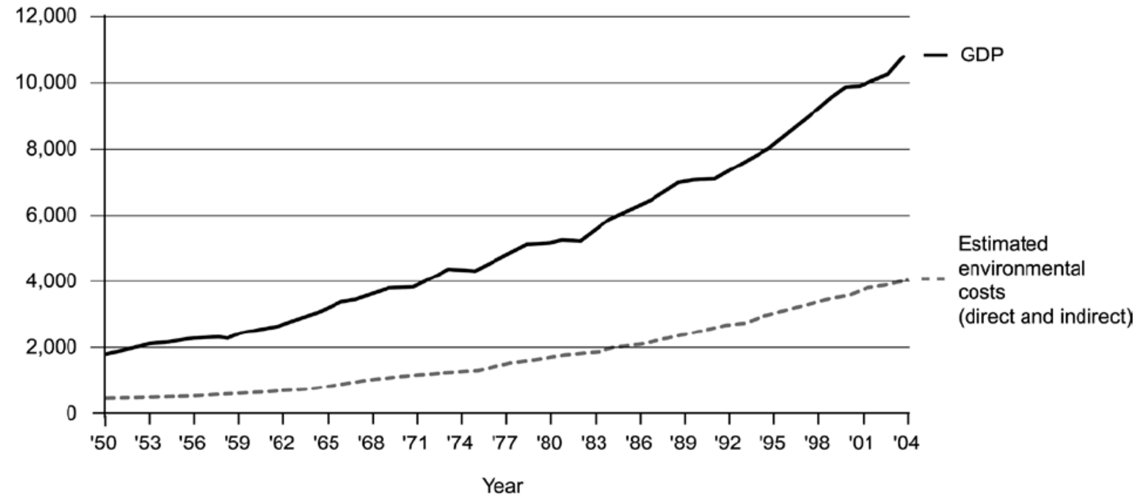

Figure 1. Gross Domestic Product vs. Estimated Environmental Costs (billions) for the US from 1950-2004
Source: Data reinterpreted by K. Hargroves from J. Talberth *et al* [5], and presented in M. Smith et al (2010) [6]

This attachment – or 'coupling' – of negative environmental pressures to economic growth has been observed in each of the five key areas listed above. In each area there are also examples of opportunities to 'decouple' economic growth from these negative pressures. For example:

- Greenhouse gas emissions: In 2006 a study on the economics of climate change estimated that each year on average the cost to the global economy of not acting to reduce greenhouse gas emissions could be the order of 5-20% of GDP, compared to an estimated 1% cost of acting to stabilise emissions [2]. The UK Government's 'Code for Sustainable Homes' is the first national legislation to set minimum standards for energy performance in new homes, calling for reductions in energy use compared to 2006 standards of 25 per cent by 2010, 44 per cent by 2013, and 100% (zero emissions) by 2016. [7]
- Biodiversity: In 2006 a study on biological diversity concluded that, '*The intensification of fishing has led to a decline of large fish. In the North Atlantic, their numbers have declined by 66% in the last 50 years'* [8]. Since the early 1960s the South Korean government has initiated programs to achieve some 6 million hectares of tree planting, nearly 65 per cent of the country, to reverse deforestation from the Korean war as part of rebuilding the country. [9]
- Water Consumption: In 2004 a study on the millennium development goal of halving the population without access to water and sanitation by 2015 estimated that this would cost in the order of US$10 billion annually, and the cost of not achieving it would be in the order of US$130 billion annually. [10] In Bogor, Indonesia, the water tariff was increased from US$0.15 to US$0.42 per cubic meter, resulting in households decreased demand by 30%. In São Paulo, when effluent charges for industry were introduced, three industries decreased their water consumption by 40-60 per cent. [11]
- Waste Production: In 2001 leading environmental business advocate Amory Lovins concluded, '*It is extremely profitable to wring out waste, even today when nature is valued at approximately zero, because there is so much waste - quite an astonishing amount after several centuries of market capitalism'*. [12] In 2006 the European Union released its 'Restriction of Hazardous Substances' (RoHS) Directive that then triggered an international response with the percentage of RoHS-compliant manufacturers rising from 51% to over 93% in nine months, [13] and aligned policies were introduced in China in 2007 and in South Korea in 2008.
- Air Pollution: In 2006 a study on agricultural economics estimated that reductions in crop yields from tropospheric ozone in Europe was in the order of €4.4-9.3 billion/year, [14] with a succession of agreements by European countries resulting in a decrease in sulphur and other air emissions. The 1983 'Convention of Long Range Trans-boundary Air Pollution' set a target for emission reduction of 30 per cent compared to 1980 levels. The Convention was updated twice, and was followed by the 1994 'UNECE Second Sulphur Protocol', which set a target for emission reduction of 50 per cent by 2000, 70 per cent by 2005, and 80 per cent by 2010. [15]

Action to achieve decoupling across entire economies will call for significant reorientation of systems, legislation, standards, practices etc and may pose the most significant challenge to the human race in its history. Consider the example of reducing greenhouse gas emissions, as presented in '*Cents and Sustainability*'. It is now well established that absolute decoupling is required to achieve a stabilisation of atmospheric concentrations of greenhouse gas emissions in the order or 450 – 550 parts per million by 2050, to avoid dangerous climate change. [2]

There are a range of scenarios for achieving this goal that are affected by the rate at which emissions are reduced over time. Firstly the current growth in emissions needs to be stopped to create the peak of the absolute decoupling curve requiring a focus on short-term performance, and secondly the levels of emissions across entire economies need to be gradually reduced each year over some 30 to 50 years, requiring a medium to long term strategy. The level of sustained reduction is dictated by the timing and height of the peak with

Figure 2 showing that peak in say 2020 will result in a lower annual reduction target than a peak in 2030 with both curves achieving 550ppm.

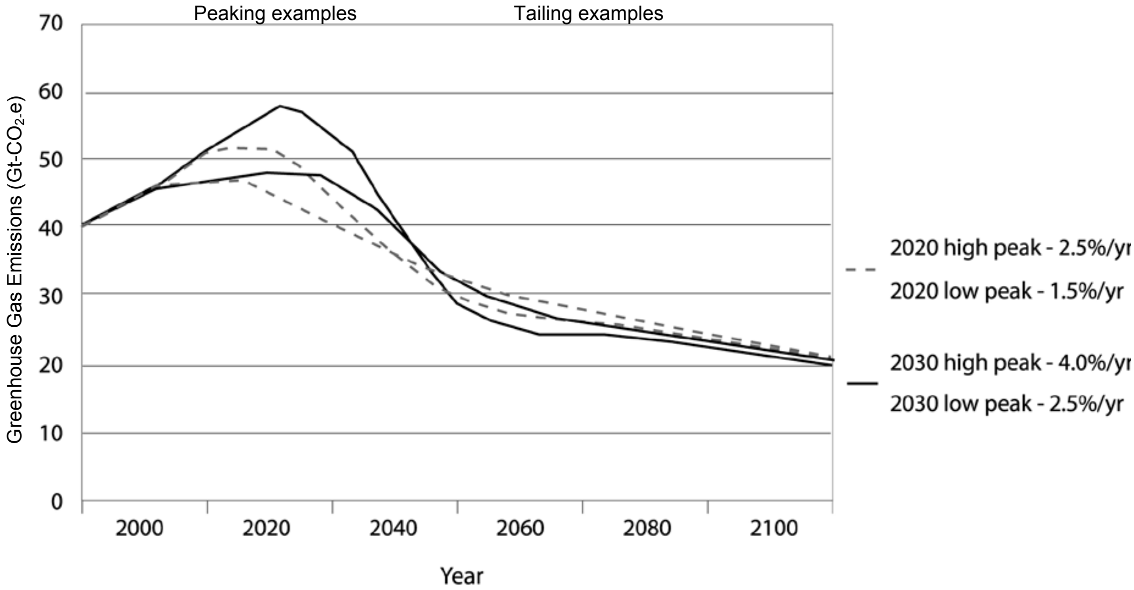

Figure 2. Illustrative emissions pathways to stabilise greenhouse gas emissions at 550ppm CO_2e, related to global GDP cost implications
Source: Adapted from Stern [2]

Education for the 21st Century

In 2011 the authors presented a schematic of curriculum transitions that have accompanied technological progress since the industrial revolution. Following each wave the higher education system undertook a curriculum renewal transition to update programs with the new innovations and applied them to the specific discipline and the needs of the employers of graduates. As the level of innovation in knowledge and skills has progressively increased with each wave this has called for increasingly larger scale efforts to achieve the associated curriculum renewal transition. As the sixth wave has and will continue to create a significant amount of knowledge and skills - and considering that there is a serious time imperative to achieve significant reductions in environmental pressures - the challenge to update programs in the next two decades will be the greatest challenge the education system has ever faced.

A typical (or 'standard') process of undergraduate curriculum renewal – i.e. to integrate an emergent knowledge and skill set – for an accredited program (including for example engineering, architecture, planning, law, business or education) may take 3-4 accreditation cycles of approximately 5-year intervals [15]. With this in mind, the time to fully integrate a substantial new set of knowledge and skills within all year levels of a degree will be in the order of 15-20 years. Further as the average pathway for a graduate is approximately 2-4 years, from enrolment to graduation, followed by 3-5 years of on-the-job graduate development, if institutions take the typical approach to fully renew such bachelor programs, this will result in a time lag of around 20 – 28 years; hence it will be some 2-3 decades before students graduating from fully integrated programs will be in decision-making positions using current methods. For postgraduate students the time lag will be shorter as students may already be practising in their field and will return to positions of influence, however accounting for the time to renew programs the time lag is in the order of 8-12 years, depending on the pace and effectiveness of curriculum renewal efforts. Clearly both timeframes are well beyond the timeframes needed to significantly reduce a range of environmental pressures as outlined previously. We refer to this as a 'time lag dilemma' for the higher education sector where the usual or ‘standard’ timeframe to update curriculum for professional disciplines is too long to meet changing market and regulatory requirements for emerging knowledge and skills.

In hindsight, if institutions had acted on the major previous calls for capacity building related to sustainability, such as in *Our Common Future* in 1987, then the standard processes may have been sufficient over the subsequent 20-30 years. However, this window for such a response has well and truly closed. Hence the urgency and complexity of the challenge to reduce environmental pressures, combined with the scope of associated knowledge and skills required to be incorporated into programs, calls for both an improvement in, and acceleration of, the standard approach to curriculum renewal across higher education. Whether in undergraduate or postgraduate education, curriculum renewal towards education for sustainable development requires immediate attention to address the critical roles of several generations of engineering professionals over the next three decades.

Internationally, there are a number of examples of government being increasingly vocal about action towards ‘Education for Sustainability’ or ‘EfS’. For example, in 2001 the South African National Quality Framework emphasized environmental education for a wide range of education institutions including higher education. [17] In New Zealand, the 2002 *Tertiary Education Strategy* includes sustainability as one of six national development objectives. [18] In the same year in the UK, the government’s *Sustainable Development Education Panel* required all UK further and higher education institutions to have staff fully trained in sustainability and providing relevant learning opportunities to students by 2010. [19]

These are all signals of a changing operating environment, which the authors have previously suggested will rapidly increase in the near future, shown stylistically to begin at a hypothetical ‘Time (*t*)’ in Figure 3. [19,20,21,22] Factors that influence the timing of ‘Time (t)’ will include the level of environmental damage and potential collapse of ecological systems such as bee communities required for wide scale pollination, fish stocks, storm surges and sea-level rises, increased natural disasters, and so on. Following ‘Time (t)’ the level of environmental performance of an organisation, business, or education institution will dictate the pace at which action is taken to comply with enforcement. Those that have done very little more than achieving the past levels of compliance will have a very steep curve that will require significant action, and those that have prepared well will have a more manageable response.

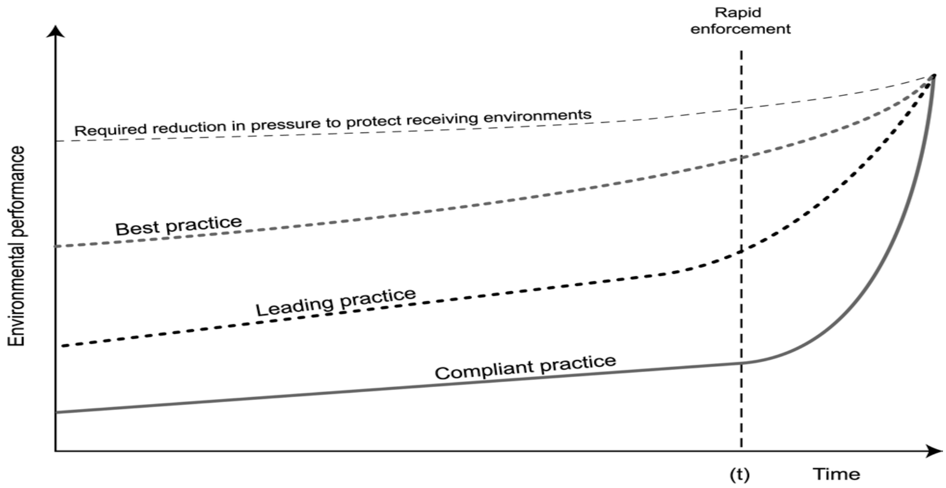

Figure 3. Stylistic representation of commitment to reducing environmental pressures [19]

Within the higher education sector, this rapid increase in compliance requirements will be evident in a range of ways, such as: regulatory and policy changes to enforce improved environmental performance in industry and business practices requiring changes to graduate attributes; professional body and accreditation agency requirements for specific graduate attributes to be included in education programs; funding agencies requiring incorporation of related topics in research grant and capital funding applications; and a significant increase in demand from potential employers for graduates with associated graduate attributes.

CONSIDERING A MULTIPLE-TRACK APPROACH

Given the scale and nature of the challenges outlined above, the authors present a whole of system approach for planning and implementing rapid curriculum renewal that addresses the critical roles of several generations of engineering professionals over the next three decades. This includes addressing the time-scale of the challenges (e.g. short, medium and long-term) and appropriate response times, followed by considering the relevant undergraduate, postgraduate and professional development opportunities:

Considering the example above relating to greenhouse gas emissions, the challenge for economies around the world is to rapidly achieve a low peaking in emissions, around 2020, to then allow a more manageable annual reduction target. The challenge of the higher education sector is that the timeframe to achieve peaking does not allow for the required knowledge and skills, which are largely yet to be incorporated into undergraduate programs, to be developed over the standard curriculum renewal timeline, meaning that it will be largely a postgraduate and professional development challenge. Further in order to prepare undergraduates to contribute to society achieving gradual sustained reductions after the peaking is achieved the standard curriculum renewal process will need to be improved and accelerated. In practice this calls for a dual focus, both on engaging with current practitioners and decision makers around knowledge and skills required to peak greenhouse gas emissions (such as postgraduate certificates, diplomas and masters programs, along with professional development seminars and short courses), and also focusing on undergraduate programs to develop knowledge and skills required to both continue to maintain the peaking and to then achieve gradual sustained reductions balanced across each sector.

In order to achieve absolute decoupling a multiple-track approach will be required for each of the major environmental pressures. For example:

- Greenhouse gas emissions: In the short-term highly energy inefficient processes and appliances can be improved to continue to deliver products and services while using significantly less energy, in many cases as much as 80% less [23]. In preparation for long-term sustained reductions in emissions low-carbon energy generation technologies need to be innovated, commercialised, and brought to scale.
- Biodiversity: In the short-term significant reductions to species losses are required with as much as 40% of species being already lost between 1970 and 2000. [24] In preparation for long-term sustained reductions in pressure on biodiversity and natural systems a range approaches to deforestation, fisheries management and control of invasive species need to be developed and implemented.
- Water Consumption: In the short-term significant reductions to freshwater withdrawal considering that groundwater extraction rates are exceeding replenishment rates by 25% in China and over 50% in parts of northwest India. [25] In preparation for long-term sustained reductions water consumption a range of forestry, agriculture and natural resource management strategies and practices need to be developed, trialled and brought to scale, such as advanced deficit irrigation strategies, holistic resource management methods, and water sensitive urban design.
- Waste Production: In the short-term significant reductions to waste generation are required considering that since 1980 the levels of annual global resource extraction have

increased by 36 per cent and is expected to grow to 80 billion tons in 2020. [26] In preparation for long-term sustained reductions waste generation a range of design, manufacturing, and recycling processes are needed to underpin structural adjustments in a range of industries.

– Atmospheric Pollution: In the short-term significant reductions to air pollution are required considering that some 10,000 people die prematurely in Delhi due to air pollution each year, equivalent to one death every 52 minutes. [27] In preparation for long-term sustained reductions in air pollution a range of new processes and methods are required to reduce emissions of sulphur dioxide, nitrous oxide, lead and particulate matter.

Such multiple-track approaches presents a significant challenge to the higher education sector as graduates and professionals need to be up skilled in areas to contribute to both agendas. As highlighted in a United Nations Environment Program report on working in a low-carbon world, '*… companies in the fledgling green economy are struggling to find workers with the skills needed to perform the work that needs to be done. Indeed, there are signs that shortages of skilled labor could put the brakes on green expansion…There is thus a need to put appropriate education and training arrangements in place*'. [28]

IMPLICATIONS FOR HIGHER EDUCATION INSTITUTIONS

Considering risks and rewards

Given that at some time in the next decade there is likely to be an increase in enforcement related to reducing environmental pressures, as with all organisations, higher education institutions will have a choice as to whether they move early or wait until enforcement ('*Time (t)*' as indicated in Figure 3). This decision will affect the level of risk and reward for the institution, with a low commitment to EFS delivering high future risk and low future reward, and a high commitment positioning institutions to capture future rewards and avoid risks, as illustrated in Figure 4. Risks include for instance falling student numbers, increasing accreditation difficulties, ineligibility for research grants, and poaching of key staff. Rewards include for example attracting the best students and staff, staying ahead of accreditation requirements, attracting research funding, securing key academic appointments and industry funding. Those institutions that are first to have a high commitment will achieve greater rewards before and after enforcement with those coming after having access to reduced rewards. Further, those who maintain a low commitment will see risks increasing before enforcement as efforts to reduce environmental pressures ramp up, and after enforcement as enforcement efforts become more stringent.

Consider a hypothetical carbon trading scheme that has just been initiated, then the large companies that currently produce high levels of emissions will likely require related competencies in their recruitment strategies. If the cost of petrol rises significantly, then society will require rapid innovation across all sectors to address the manufacture and supply of goods and services. Mechanical and electrical engineers will be expected to design more efficient processes, equipment and vehicles, and civil engineers will be expected to design more efficient transport systems and infrastructure. In the face of such rapid shifts, departments that are unprepared could face increasing accreditation difficulties, falling student numbers, with the potential for staff loss and restricted research opportunities even before the period of enforcement. In addition, their graduates will be less employable. Such reduced performance may also call for drastic measures, such as restructuring, as a result of the struggle to deal with accreditation, students and staff retention, especially post-t.

The benefits curve may also be affected as the supply of graduates with sustainability knowledge and skills subsequently catches up with employer demand, flattening over time, particularly post-t. For departments producing graduates with few competitors, their graduates are likely to be in demand. However, as more institutions develop graduates with the desired traits, a department's efforts in curriculum renewal may actually just be keeping up, rather than creating a new and innovative market niche.

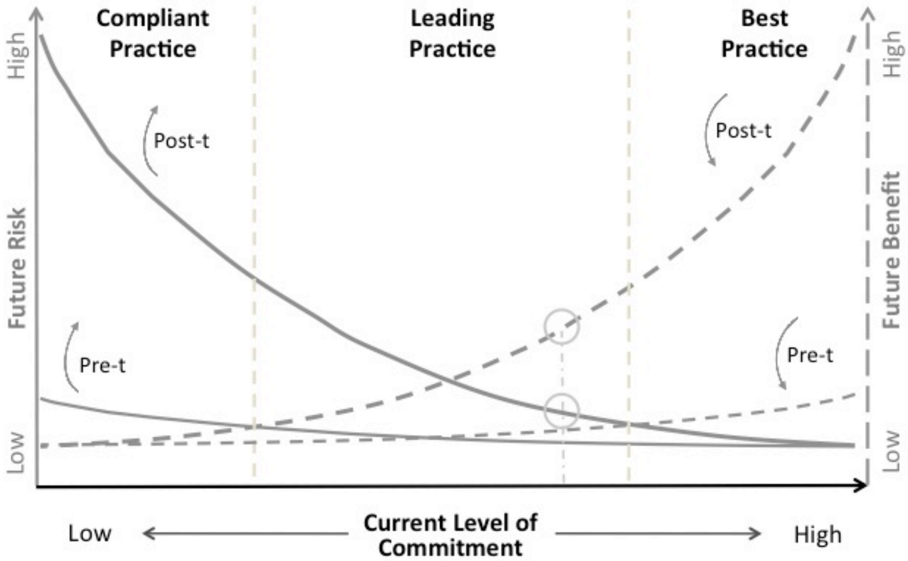

Figure 4. Risk and reward scenarios for curriculum renewal in higher education [19]

This situation presents significant cause for universities and departments to rethink their strategies related to curriculum reform in order to minimise the risks and capture the rewards. In short, over the coming years, departments who do not transition their programs to incorporate sustainability are likely to find it increasingly difficult to operate. This is so particularly in some jurisdictions where the engineering accreditation board has a strong influence on the general direction of program curricula. Furthermore, the traditional roles of universities as providers of education for professionals may be challenged by private training providers who explore niche education opportunities in capacity building in topics related to sustainability, along with firms and government departments developing in-house capacity building programs that assume a base-line graduate capacity.

Rethinking the business plan

When an institution or department commits to *EfS* one of the first considerations is the time frame that curriculum renewal can be undertaken. When considering timings for a curriculum renewal transition there are two bounds, firstly institutions can wait until enforcement (i.e. adopting 'standard curriculum renewal' or 'SCR' processes) and then move rapidly (i.e. through 'rapid curriculum renewal' or 'RCR' processes) to comply along with the rest of the sector. This is shown as the '*post-t*' transition curve in Figure 5. Alternatively, institutions could move rapidly ahead of future compliance (shown as '*pre-t*' transition) and capture the associated benefits. Within the shaded area inside the upper and lower bounds of the envelope in Figure 5, there are an infinite number of possible transitions, including a staged stepping up from '*compliance*' to '*leading practice*' to '*best practice*'.

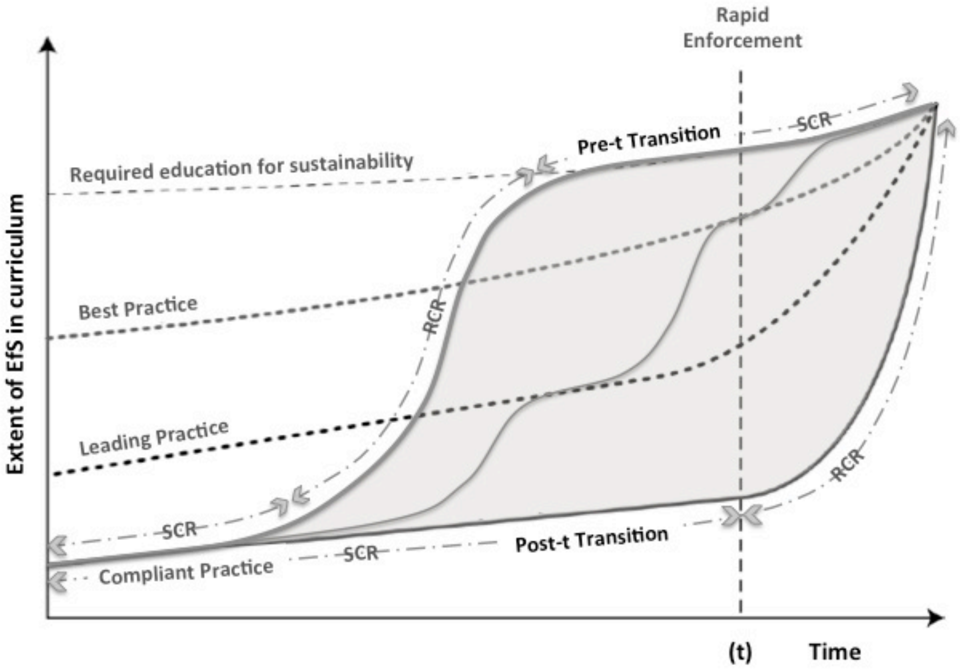

Figure 5. A stylistic representation of the possible curriculum renewal transition curves for education institutions to incorporate education for sustainability ('SCR' Standard Curriculum Renewal; 'RCR' Rapid Curriculum Renewal). (Adapted from [22])

As society is undergoing the transition concurrently, it will be important to contribute graduates who can lead, but not be too far ahead of the reality at their time of graduation. For example, as part of the transition towards more sustainable civil infrastructure, society's 'old industry' plant and equipment such as fossil fuel power stations and centralised electricity grids will still require service and maintenance by professionals with 'old industry' knowledge and skills. The balance of 'old' and 'new' needs to be carefully managed to consider to the need to reduce environmental pressures, the needs of society, and employer demands. As there is a large amount of embedded infrastructure (for example roads, bridges, power stations, electricity grids etc) to be managed, maintained and transitioned, requiring 'old industry' education, integrating 'new industry' content too quickly could be problematic if graduates don't have the skills that the employment market needs at the time that they graduate.

Managing strategic and systematic curriculum renewal

At the level of the institution, there will need to be new strategies and structures to incorporate the *EfS* agenda into existing operational frameworks across the many arms of the institution or department – including governance and management, curriculum design and innovation, operations and facilities, marketing, human relations, and stakeholder relations. Departments will also need to find funds to support the transition, including increasing internal professional capacity, and recruiting staff who can deliver the required curriculum. It will also need to promote such opportunities to potential students, and anticipate shifts in student enrolment.

As discussed above, the operating environment is still predominantly 'Pre-t'. Within this context, a growing number of organisations, alliances and networks have emerged over the last decade, committed to integrating *EfS* into the curriculum, as highlighted in Table 1.

Table 1. Examples of university alliances promoting EfS

Alliance	Brief Description
University Leaders for a Sustainable Future (ULSF)	Since 1992, ULSF has served as the Secretariat for signatories of the Talloires Declaration, a ten-point action plan committing institutions to sustainability and environmental literacy in teaching and practice. Over 350 university presidents and chancellors in more than 40 countries have joined by signing the declaration.
Higher Education Partnership for Sustainability (HEPS) programme	One of the earlier university alliance initiatives was a three-year UK partnership (2001-2003) of 18 Higher Education institutions committed to sustainability supported by the funding councils of England, Northern Ireland, Scotland and Wales. Co-ordinated by *Forum for the Future* the partnership worked to generate transferable tools, guidance and inspiration, to demonstrate the potential the integrating sustainability in the higher education sector. [29]
Global Higher Education for Sustainability Partnership (GHESP)	Comprising the International Association of Universities (IAU) the University Leaders for a Sustainable Future (ULSF) Copernicus-Campus and UNESCO, GHESP aims to mobilise higher education institutions to support EfS, focusing on responding to Chapter 36 of *Agenda 21* regarding the role of education.
Association for the Advancement of Sustainability in Higher Education (AASHE)	AASHE is a member organisation of colleges and universities in the US and Canada working to create a sustainable future. The *AASHE Bulletin* is the leading news source for campus sustainability in North America, and the *AASHE Digest* is an annual compilation of Bulletin items. AASHE has developed a standardised campus sustainability rating system called STARS (Sustainability Assessment, Tracking & Rating System), launched in 2009.
American College & University Presidents Climate Commitment (ACUPCC)	The ACUPCC is an initiative of presidents and chancellors to address global warming by committing to climate neutral campuses and by providing the education and research to enable society to do the same. Nearly 600 US college and university presidents have signed the commitment and are publicly reporting progress, including greenhouse gas emission reports and Climate Action Plans.
Higher Education Associations Sustainability Consortium (HEASC)	HEASC is an informal network of higher education associations with a commitment to advancing sustainability within their constituencies and within the system of higher education itself. This includes developing in-depth capability to address sustainability issues.

There are also a number of emerging non-profit partnerships that are working to facilitate capacity building for sustainability, extending beyond higher education institutions into professional associations, industry and government. For example, Second Nature is a US non-profit organization that since 1993 has worked with more than 4,000 faculty and administrators at more than 500 colleges and universities to help make the principles of sustainability fundamental to higher education. Led by one of the world's leading *EfS* experts Dr Anthony Cortese, the organization's successes include advancing networks at the state, regional, and national levels, and conducting a multi-million dollar, ten-year advocacy and outreach effort that was instrumental in launching and maintaining momentum within the higher education EfS movement in the US, through AASHE and the HEASC (see table above). The US Partnership on Education for Sustainable Development was formed to leverage the UN Decade to foster EfS in the US. [30] Led by another of the world's EfS leaders Dr Debra Rowe, it comprises individuals, organizations and institutions with a vision of sustainable development being fully integrated into education and learning in the country. One of its actions has been to initiate and sponsor the Disciplinary Associations Network for Sustainability (DANS), an informal network of professional associations working on professional development, public education, curricula, standards and tenure requirements to reflect sustainability, and legislative briefings on what higher education can bring to sustainability related policies. [31]

CONCLUSIONS

In this paper the authors have discussed a challenge within the higher education sector in considering capacity building for 21^{st} Century engineering, where the timeframe to decouple economic growth from environmental pressure does not allow for the required knowledge and skills which are largely yet to be incorporated into undergraduate programs, to be developed over the standard curriculum renewal timeline, meaning that it will be largely a postgraduate and professional development challenge. Further in order to prepare undergraduates to contribute to society achieving gradual sustained reductions after the peaking is achieved the standard curriculum renewal process will need to be improved and accelerated.

The implication of this challenge requires an immediate multiple-track approach to curriculum renewal in engineering education, engaging with current practitioners and decision makers around knowledge and skills (such as postgraduate certificates, diplomas and masters programs, along with professional development seminars and short courses), and also focusing on undergraduate programs to develop knowledge and skills. This approach is within the context of varying but nevertheless increasing focus by program accreditation boards on EfS, where the time of regulatory and market enforcement (time 't') may have already arrived or is imminent.

It is clear that are many challenges and opportunities facing the higher education sector. Indeed there are many knowledge and skill considerations, organizational aspects, and pedagogy implications to interweave into a curriculum renewal process, in a time-constrained and often resource-poor institutional environment. With the rapid emergence of organisations and commitments to *EfS*, and with the complexity of the response required to embed sustainability within the engineering curriculum, it is observed that organisations with robust existing frameworks have an advantage in undertaking rapid curriculum renewal.

REFERENCES

[1] The Natural Edge Project, www.naturaledgeproject.net, accessed 21 April 2012.

[2] Stern, N. (2006) *The Stern Review: The Economics of Climate Change*, Cambridge University Press, Cambridge.

[3] Gore, A. (2006) *An Inconvenient Truth*, P. C. a. P. Productions.

[4] Diamond, J. (2005) *Collapse: How Societies Choose to Fail or Succeed*, Penguin Books, New York.

[5] Talberth, J., Cobb, C. and Slattery, N. (2006) *The Genuine Progress Indicator 2006: A Tool for Sustainable Development,* Redefining Progress, Oakland, California

[6] Smith, M., Hargroves, C. and Desha, C. (2010) 'Figure 2.7 Gross Domestic Product vs. Estimated Environmental Costs (billions) for the United States of America from 1950-2004', in *Cents and Sustainability - Securing Our Common Future by Decoupling Economic Growth from Environmental Pressures*, Earthscan, London.

[7] Department for Communities and Local Government (2006) 'Code for Sustainable Homes: A step-change in sustainable home building practice', Crown Copyright Rajgor, G. (2007) 'Countdown to zero emissions', *Refocus*, vol 8, no 1, pp60-61.

[8] CBD (2006) *Global Biodiversity Outlook 2*, Secretariat of the Convention on Biological Diversity (CBD), Montreal

[9] Chong, S.K. (2005) 'Anmyeon-do Recreation Forest: A Millennium of Management', in Durst, P. et al (eds), *In Search of Excellence: Exemplary Forest Management in Asia and the Pacific*, Asia-Pacific Forestry Commission, FAO Regional Office for Asia and the Pacific, Bangkok, pp251-259.

[10] UNECE (1979-2005) *The Convention on Long-range Transboundary Air pollution*, United Nations Economic Commission for Europe, Geneva

[11] Hutton, G. and Haller, L. (2004) Evaluation of the Costs and Benefits of Water and Sanitation Improvements at the Global Level, Water, Sanitation and Health, Protection of the Human Environment, World Health Organization, Geneva
[12] Lovins, A. (undated) 'Amory Lovin's Natural Capitalism Lecture', *ABC: The Slab*, Australia.
[13] Global Sources (2005) RoHS compliance readiness survey: mainland China, Taiwan, Hong Kong and South Korea, Global Sources, p3.
[14] Holland, M., Kinghorn, S., Emberson, L., Cinderby, S., Ashmore, M., Mills, G. and Harmens, H. (2006) *Development of a framework for probabilistic assessment of the economic losses caused by ozone damage to crops in Europe,* CEH project No. C02309NEW, Centre for Ecology and Hydrology, Natural Environment Research Council, Bangor, Wales.
[15] UNECE (1994) *The 1994 Oslo Protocol on Further Reduction of Sulphur Emissions*, United Nations Economic Commission for Europe, Geneva.
[16] Desha, C., Hargroves, K. and Smith, M. (2009) 'Addressing the time lag dilemma in curriculum renewal towards engineering education for sustainable development', *International Journal of Sustainability in Higher Education*, vol 10, no 2, pp184-199.
[17] Rensburg, E., Lotz Sisitka, H. and Mosidi, S. (2001) *Environmental Learning Across NQF*, Department of Environmental Affairs and Tourism, South Africa
[18] Parliamentary Commissioner for the Environment (2004) *See Change: Learning and education for sustainability*, Wellington, New Zealand
[19] Sustainable Development Education Panel (2002) Learning to Last: Business and Sustainable Development - a Learning Guide for Sector Skills Councils.
[20] Byrne, E., Desha, C., Fitzpatrick, J. & Hargroves, K. (2010). Engineering Education For Sustainable Development: A Review Of International Progress, in *proceedings of the 3rd International Symposium for Engineering Education*, 2010, University College Cork, Ireland.
[21] Desha, C. & Hargroves, K. (2011) 'Informing engineering education for sustainable development using a deliberative dynamic model for curriculum renewal', in *proceedings of the Research in Engineering Education Symposium*, 2011, Madrid.
[22] Desha, C. and Hargroves, K. (2012) 'Fostering rapid transitions to Education for Sustainable Development through a whole system approach to curriculum and organizational change', in *proceedings of the 2012 World Symposium on Sustainable Development at Universities*, Rio de Janeiro, 5-7 June 2012.
[23] von Weizsäcker, E., Hargroves, K., Smith, M., Desha, C. and Stasinopoulos, P. (2009) *Factor 5: Transforming the Global Economy through 80% Increase in Resource Productivity*, Earthscan, UK and Droemer, Germany.
[24] CBD (2006) *Global Biodiversity Outlook 2*, Secretariat of the Convention on Biological Diversity (CBD), Montreal.
[25] Briscoe, J. (2008) India's Water Economy: Bracing for a Turbulent Future, World Bank, Washington DC.
[26] OECD (2008) *OECD Environmental Outlook to 2030*, OECD, Paris, pp246, 249.
[27] CSE (1999) 'Sick of Air Pollution', Press Release, Centre for Science and Environment, 5 June 1999.
[28] United Nations Environment Programme (2008) *Green Jobs: Towards Decent Work in a Sustainable, Low-Carbon World*, United Nations
[29] Forum for the Future (2004) 'Tip for Top in Higher Education: Forum's Learning in Action conference pushes the SD solutions', www.forumforthefuture.org.uk/greenfutures/articles/601773, accessed 21 January 2011.
[30] The US Partnership for Education for Sustainable Development (n.d.) 'The US Partnership for Education for Sustainable Development', http://usp.umfglobal.org/main/view_archive/1, accessed 21 April 2012
[31] DANS (n.d.) 'Mission and Action Plan for the Disciplinary Associations Networks for Sustainability', www.aashe.org/dans/about.php, accessed 21 April 2012.

Biographical Information

Dr Cheryl Desha is a lecturer in sustainable development in the Science and Engineering Faculty (School of Earth, Environment and Biological Systems), Queensland University of Technology, Australia. She is also a principal researcher with The Natural Edge Project research group (TNEP), an academic partnership for research and capacity building for sustainable development. Cheryl and the TNEP team have developed a number of internationally renowned books on sustainable development including ‘Factor Five’, ‘Cents and Sustainability’, ‘Whole System Design’, and ‘The Natural Advantage of Nations’. Her PhD and post-doctoral research focuses on rapid curriculum renewal, grounded in capacity building for sustainable development and engineering education. This includes developing and trialing models and approaches to embedding new knowledge and skills, from trans-disciplinary inquiry into curriculum renewal theory and organizational change theory in the context of urgent and challenging times.

Charlie Hargroves is the Sustainable Development Fellow at the Entrepreneurship, Commercialization and Innovation Centre, University of Adelaide, Australia. He is also a co-founder and a principal researcher with The Natural Edge Project research group (TNEP), an academic partnership for research and capacity building for sustainable development. Charlie and the TNEP team have developed a number of internationally renowned books on sustainable development including ‘Factor Five’, ‘Cents and Sustainability’, ‘Whole System Design’, and ‘The Natural Advantage of Nations’. His doctoral research with Professor Peter Newman focuses on adaptive governance and knowledge strategies for carbon structural adjustment, focusing on: implementation of new and innovative technology and processes; renewal of higher education programs and professional development; and efforts by local municipalities to encourage community behaviour change.

Corresponding author
Dr. Cheryl Desha
Queensland University of Technology
Room 774, S Block, Gardens Point Campus
2 George Street, Brisbane QLD 4001
+61 7 3138 4072
cheryl.desha@qut.edu.au